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AUTHOR DeLuca, Frederick P.
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ABSTRACT

An electronic apparatus, designed and constructed to be an equivalent of Piaget's first chemical experiment, was assessed in terms of reducing discriminatory and administration difficulties often criticized in Piagetian tasks. In this study, the chemical task and its electronic equivalent were included in a battery of five tasks and were randomly switched between first and fifth positions in order of administration. The battery was administered to 64 intermediate-ability twelfth-grade chemistry students (mean age 17 years 7 months). Contingency matrixes were constructed for the comparison of tasks and sex, order of tasks and between tasks. Times for administration of chemical (mean time = 14 min.) and electronic (mean time = 4.4 min.) tasks were recorded. Statistical analyses of the data revealed that both tasks were sex-free and equally effective in discriminating between concrete and formal operational subjects. The electronic task provided several advantages: (1) better control of the variables; (2) more compact and easily transported; and (3) less time consuming than the chemical task in administration. (CS)

MEASUREMENT OF LOGICAL THINKING: AN ELECTRONIC EQUIVALENT OF PIAGET'S FIRST CHEMICAL EXPERIMENT

by

Frederick P. DeLuca
Department of Earth Sciences
253 Science Hall I
Iowa State University
Ames, Iowa 50011

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of the National Association for
Research in Science Teaching
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MEASUREMENT OF LOGICAL THINKING: AN ELECTRONIC EQUIVALENT OF PIAGET'S FIRST CHEMICAL EXPERIMENT

The current trend toward increasing amounts of research based on Piaget's theory of intellectual development appears to hold high potential for advancing knowledge of the learning process. It is doubtful, however, that significant gains will be realized unless improvements and/or alternatives to the use of piagetian tasks are developed (Ayer, 1971). This view is based on several factors that tend to restrict the usefulness of piagetian tasks. For example, many piagetian tasks are suspected of containing misleading perceptual cues which retard the success of field dependent subjects (Pascual-Leone, 1969: Case, 1974): some tasks discriminate against female subjects (Lawson, 1975: Dale, 1970): materials are bulky: and a relatively long time is required to administer tasks.

The purpose of this investigation was to make a preliminary assessment of the possibility of transforming Piaget's first chemical task (Inhelder and Piaget, 1958) into an electronic equivalent (electronic task, ET) which would retain or improve upon the advantages of the chemical task (CT) while reducing the disadvantages mentioned above. Sixty-four twelfth grade students were tested with the CT and the ET. The independent variables were tasks, order of administration of tasks, and sex of the students. The dependent variables were intellectual development and amount of time required to administer each task. If the two tasks were indeed equivalent in terms of logical thinking and psychological context for male and female students, then a significant correlation should exist between students' scores on both tasks, and male and female students should score equally well on both tasks. If misleading perceptual cues are reduced by the ET, it should yield higher scores than those on the CT. Less time should be required in administering the ET because students can manipulate combinations of switches more rapidly than combinations of chemical.

If an instrument--which is equal to or better than the CT in measuring formal thought involving the use of combinations, and which is also simpler to administer--can be developed, then classroom teachers would be more willing to use it (in conjunction with other techniques) and thereby gain more insights into the vast range of intellectual levels that exists among students in most classrooms. Such insights should be helpful in promoting a greater effort toward the implementation of curricula and instruction that better articulate with the intellectual level of each student.

METHOD

Subjects

The subjects (Ss) for this study were 64 (28 males and 36 females) intermediate ability twelfth graders enrolled in chemistry. The age of the Ss ranged from 17 years-2 months to 18 years-4 months with a mean age of 17 years-7 months.

Measuring Instruments

Piaget's first chemical experiment was described by Inhelder and Piaget (1958), and replicated by Dale (1970). An electronic equivalent of the task was designed and constructed (Figure 1). The change from clear solution to yellow solution was simulated by the lighting of a light emitting diode (LED). Four toggle switches simulated the four chemicals. A normal-off, push-on switch acted as the indicator for each combination of one or more switches in the on position. The entire circuit was housed in an aluminum box 5 centimeters wide by 4 centimeters deep by 10 centimeters long, and was powered by two pencil cells. Switches number 1 and 3 combined to turn the light on, switch 2 did not affect the light, and switch 4 inhibited the light. The CT and the ET required the same combinations and was logically similar (DeLuca, 1975).

Administration of the Tasks

The CT and ET were included in a battery of five tasks, and were randomly switched between the first and fifth positions in the order of administration. The other three tasks served as a buffer and always occupied the same positions--second, third, and fourth. This procedure balanced the carry-over of learning between the CT and ET.

The CT was administered according to procedures described by Inhelder and Piaget (1958), but with some modifications. The Ss in this study were told that the chemical (indicator) in the small bottle was necessary for the color change and to ignore the milky color when it resulted from combining two of the chemicals. These modifications were necessary in order to better match the protocol for the ET.

Ss on both tasks were given the key combinations (1+3, 1+2+3) if they could not find or recall them prior to the question concerning the isolation and role of each chemical or switch. Without this procedure it was impossible to determine whether failure to solve the problem was due to lack of formal operations, failure to recall key combinations, or inadvertent omission of one or both combinations. The importance of recall in evaluating Ss' responses to piagetian tasks has been discussed extensively by Bryant (1974) and also reported by Dale (1970).

All switches of the ET were in the off-position when Ss were introduced to the task. The Ss were given directions similar to those for administration of the CT, and they were told to feel free to move any toggle switches, to test for the light by depressing the red push-button switch, and to return all switches to their off-position before the next try. No toggle switches were moved while the red push-button switch was on. This procedure prevented switching action that was analogous to the entry and removal of a chemical from a test tube.

Scoring

Ss' scores were based on their ability to search for combinations, to discover and recall key combinations, and to isolate chemical (switch) 2 as not necessary and chemical (switch) 4 as an inhibitor. The relative difficulties in discovery and recall of key combinations, and the isolation of chemicals 2 and 4 were formulated into a 36 point hierarchy. Based on data from Dale's (1970) study it was determined that discovery and recall of combination 1+2+3 was more difficult than discovery and recall of combination 1+3. Discovery and recall of either combination was more difficult than discovery but no recall, which in turn was more difficult than no discovery. Likewise chemical 2 (not necessary) was more difficult to isolate than chemical 4 (inhibits), and the isolation of both chemicals 2 and 4 was more difficult than any form of discovery or recall.

Separate search (for combinations) scores were calculated and added to the Ss' scores on the hierarchy. The search scores were based on the total of 16 possible combinations, and were calculated by subtracting the sum of repeated and omitted combinations from 16, dividing by 2, and rounding-off to the next highest whole number if a fraction resulted.

The total 44-point range was divided into piagetian sub-stages which approximate the general levels reported by Dale(1970). Formal-IIIB, 36-44 points, isolate both chemicals (switches) 2 and 4, plus the discovery of at least one key combintion, plus a sufficient search score (0-8) to total to at least 36 points. Formal-111A, 18-35 points, isolate chemical 2 or both chemicals 2 and 4, plus the discovery of at least one key combination, plus a sufficient search score (0-8) to total to at least 18 points. Concrete-IIB, 10-17 points, fail to isolate, or isolates only chemical 4, plus a sufficient search score (0-8) to total to at least 10 points. Concrete-IIa, 4-9 points, fails to isolate either chemical 2 or 4, plus any combination of discovery and recall, plus a sufficient search score (0-8) to total to at least 4 points.

Results

The means and standard deviations for scores of males and females on the CT and ET are presented in Table 1.

Contingency matrices for the comparison between tasks, between tasks and sex, and between order of tasks are shown in Table 2. The original 3x3 contingency tables are reduced to 2x2 in order to avoid cells with expected frequency counts below 5 and the inflated chi-squares that would result. Scores of 27 or greater were categorized as "High", and scores of 26 or less were categorized as "Low". "High-High" indicated that scores on both the CT and ET were 27 or greater, and "Low-Low" indicates both scores were 26 or less.

Part A of Table 2 compares the scores between the CT and ET. A chi-square analysis of the data indicated a significant relationship between the two tasks ($x^2 = 33.26$, $p < .001$). The phi coefficient of correlation between the two tasks was .72. Part B compares task scores with the sex of the Ss. A chi-square analysis of the data indicated no significant relationship between task scores and sex. Part C compares the tasks scores and the order in which the two tasks were taken. A chi-square analysis of the data indicated no significant relationship between task scores and order in which the task scores were taken.

Time for administration of the chemical task ranged from 11 to 22 minutes with a mean time of 14 minutes per S. Time for administration of the electronic task ranged from 3.2 minutes to 6.5 minutes with a mean time of 4.4 minutes per S.

Discussion, Conclusions, and Implications

The results of this study support the equivalency of the CT and ET. Male and female Ss perform equally well on both tasks, and a moderately stong correlation (phi = .72) exists between scores on both tasks. The average time required to administer the ET is 3 times less than the time required to administer the CT. The ET can be easily held in one hand and readily transported, whereas the CT requires bulky materials and a source of water for washing test tubes.

The charge that piagetian tasks contain misleading perceptual cues has not been supported by this study. One reason could be that the investigator's desire to standardize protocols tended to reduce the impact of any misleading perceptual cues that existed in the CT. Another possibility is that the majority of the subjects may have been field independent thinkers (Case, 1974) and were not mislead by irrelevant perceptual cues.

Tangential to the focus of this study, but perhaps equally substantive, are the procedures utilized to control for recall of key combinations and to facilitate scoring. In the past, researchers have failed to control for recall on the CT, and displeasure with the task (Neimark, 1970) may have been brought about by chance fluctuations in recall. The scoring technique in this study attempts to account for and qualify all possible responses to the task while providing for flexibility among Ss. It appears to have functioned reasonably well. But of course, these and the total concept of the ET must be subjected to more study before any firm conclusions can be made.

The ET could have a significant impact on future research and educational testing. The ET can serve as the prototype for the transformation of other piagetian tasks. Modern electronics can simulate almost any level of thinking, so ETs need not be restricted to Piaget's ideas; they can also reflect original and creative designs. Interfacing Ss with ETs constitutes progress in measurement because such action provides sharp control of variables and automatically makes possible the use of modern electronics to collect, store, and process data in new and more efficient ways. The application of recent advances in electronic technology makes it possible to have subjects interact with a battery of ET's, and have the data automatically processed on site with micro-computers and/or by using a transportable link to interface with large fixed base computers.

Robert Karplus of the University of California, Berkeley, is heading a team which is conducting workshops, on a national level, to advance science teaching through better understanding of the development of reasoning. The development and application of simple techniques for measuring intellectual development constitutes an important part of their program. This study may aid similar efforts to advance science teaching by providing the researcher and the classroom teacher with a rapid technique for measuring formal thought involving the use of combinations. Just as piagetian tasks helped Piaget to develop his theory of intellectual development, they can also help teachers to understand and perhaps apply his theory to the teaching of science.

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TABLE 1

Means and Standard Deviations for Scores on the Chemical, and Electronic Tasks

	Males (N-28)		Females (N-36)	
	Mean	Standard Deviation	Mean	Standard Deviation
Chemical Task	28.43	12.83	26.81	12.38
Electronic Task	29.71	13.74	26.06	13.18

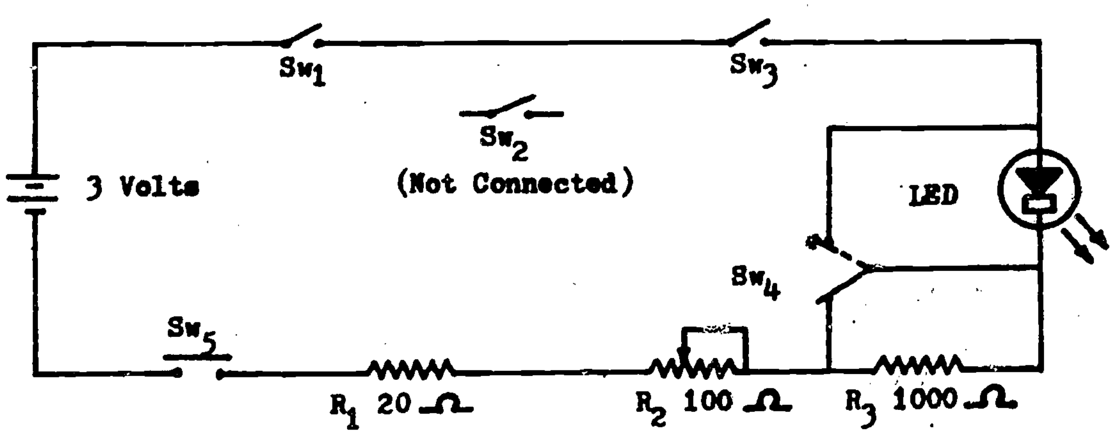

Figure 1. Circuit diagram of the electronic task

TABLE 2

Contingency Tables Comparing Chemical/Electronic Tasks, Tasks/Sex, and Tasks/Order

A) Tasks

		Chemical Task Levels	
		High	Low
Electronic Task Levels	High	30	6
	Low	3	25

$x^2 = 33.26$, $p < .001$ Significant
Phi = .72

B) Sex

	Chemical-Electronic Task Levels	
	High-High	Low-Low
Males	16	12
Females	14	13

$x^2 = .15$, $p < .68$ NS

C) Order of Tasks

	Chemical-Electronic Task Levels	
	High-High	Low-Low
Chemical First	20	14
Electronic First	10	11

$x^2 = .65$, $p < .42$ NS